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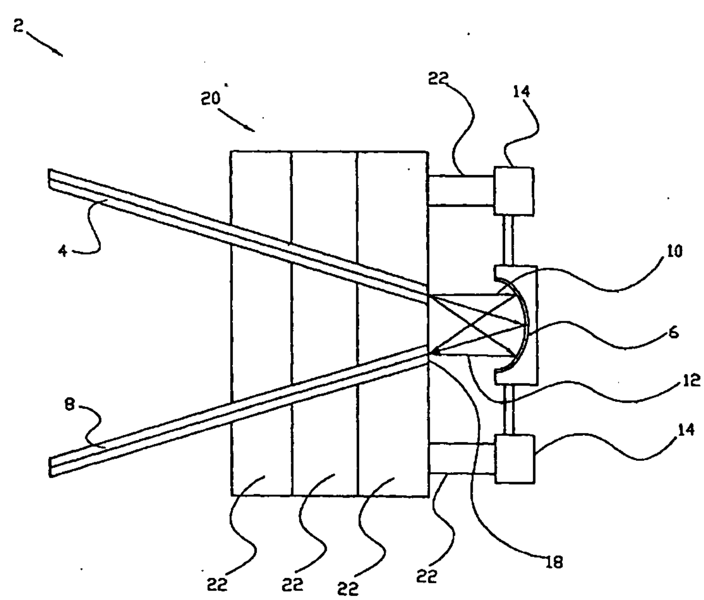
(54) Title: A VARIABLE OPTICAL ATTENUATOR WITH A MOVEABLE FOCUSING MIRROR



(57) **Abstract:** A variable optical attenuator, or VOA, includes a movable focusing mirror (6) and an actuator (14) integrated on a substrate (20) or within a MEMS. The actuator (14) moves the mirror (6) within a range of motion to reflect, focus and steer a light beam. One embodiment further includes an input (4) and an output (8) photonic component, such as wave guides or optical fibers. The wave guides or optical fibers may have angled endfaces and be positioned to reduce the required operating range of motion of the mirror. The mirror may be a Fresnel mirror, a concave mirror, a diffractive mirror or a concave diffractive mirror. In certain embodiments the mirror is moved in at least two dimensions to steer the light beam to form a trajectory having at least two dimensions.

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A Variable Optical Attenuator with a Moveable Focusing Mirror

Field of the Invention

The present invention relates generally to variable optical attenuation, and more particularly, to methods and devices for MEMS-based variable optical attenuation of optical signals.

Background of the Invention

The wide application of variable optical attenuation of optical signals within optical communications networks insures that enhancements in variable optical attenuators and attenuation methods and capabilities can improve the field of optical network technology. Innovations that increase the performance qualities and lower the cost of manufacture of variable optical attenuators, or VOAs, are also of value to communications technologists.

The prior art has attempted to improve the devices and techniques of light beam reflection by employing concave mirrors. U.S. Pat. No. 4,459, 022, Morey (July 10, 1984), discloses an apparatus that includes a concave mirror coupled with optical fibers. Morey's device uses optical fibers as position detecting elements in an electrically passive detecting head. Morey discloses an embodiment wherein a concave mirror is permanently and fixedly mounted onto a movable handle. An optical fiber directs a light beam at the concave mirror, and a plurality of output optical fibers receives portions of the light beam after reflection from the concave mirror. The reflection of the light beam

from the concave mirror to the output optical fiber is affected as a user moves the handle while changing the handle position. Observing the portions of the reflected light beam as transmitted through the plurality of output optical fibers are used to determine the position of the handle at the moment of reflection of the light beam from the concave mirror.

U.S. Pat. No. 6,031, 946, Bergmann (February 29, 2000), discloses an optical switch having two optical fibers, a concave mirror, a mirror actuator, and a mechanical actuating member attached to the mirror and to the actuator. The actuating member drives the mirror from one preset, discrete position, to another preset position, wherein each discrete mirror position provides a prespecified degree of attenuation of transmission of an optical beam from one optical fiber to another optical fiber.

There is a long felt need to improve the devices and techniques of variable optical attenuation wherein attenuation can be accomplished with more elegance and flexibility than provided in the prior art.

Summary of the Invention

A preferred embodiment of the present invention of a variable optical attenuator (VOA) for attenuating an optical signal, the optical signal transmitted via a light beam, that comprises a movable focusing mirror for reflecting, focusing and steering the light beam in a trajectory, an actuator that is operatively coupled to the movable focusing mirror and is used to move the focusing mirror an output photonic component positioned to receive at least part of the light beam reflected from the movable focusing mirror.

In accordance with the purpose of the invention, as embodied and broadly described herein, relates to a MEMS-based variable optical attenuator device (VOA) for attenuating an optical signal transmitted via a light beam that includes a substrate, a movable focusing mirror coupled with the substrate that us used for reflecting, focusing and steering the light beam to a trajectory and an actuator that is coupled to the substrate, and to the movable focusing mirror where the actuator moves focusing mirror. In addition, the MEMS-based variable optical attenuator device (VOA) also includes an input photonic component coupled to the substrate such that the light beam emitting from the input photonic component is directed toward the movable focusing mirror and an output photonic component coupled to the substrate is positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the output photonic component.

Also in accordance with the purpose of the invention, as embodied and broadly described herein, the invention relates to a MEMS-based variable optical attenuator device (VOA) for attenuating an optical signal transmitted via a light beam that includes a substrate, a movable focusing mirror coupled with the substrate that us used for reflecting, focusing and steering the light beam to a trajectory and an actuator that is coupled to the substrate, and to the movable focusing mirror where the actuator moves focusing mirror. In addition, the MEMS-based variable optical attenuator device (VOA) also includes an input wave guide having an input transmission axis and an input end face, wherein the input wave guide is coupled to the substrate and the light beam emitting along the transmission axis, from the end face of the input waveguide towards the movable focusing mirror an output wave guide having an output end face and transmission axis

such that the end face of the output wave guide is positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the output wave guide.

It is an advantage of the present invention is to provide a variable optical attenuator, or VOA that is coupled with a substrate.

It is an advantage of the preferred embodiments of the present invention is to provide a MEMS-based variable optical attenuator (VOA).

It is an object of an alternate preferred embodiment of the present invention to provide a variable optical attenuator (VOA) integrated on a substrate.

It is an alternate object of the preferred embodiment of the present invention to provide a variable optical attenuator (VOA) that includes a focusing mirror.

It is still another object of certain preferred embodiments of the present invention to provide a MEMS-based device that comprises a variable optical attenuator (VOA) .

It is yet another object of certain preferred embodiments of the present invention to provide an array of MEMS-based devices that comprise or partially comprise a multi-channel MEMS-based a variable optical attenuator (VOA).

The above summary of the present invention is not intended to describe each illustrated embodiment or every implementation of the present invention. The figures and the detailed description which follow more particularly exemplify these embodiments. Other objects, features, and advantages of the present invention will be apparent from the

accompanying drawings and from the detailed description which follows below. The invention will now be elucidated in more detail with reference to certain non-limitative examples of embodiment shown in the attached drawing figures.

Brief Description of the Drawings

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements, and in which:

FIG. 1 is a first preferred embodiment of the present invention.

FIG. 2 is a receiving face of an output wave guide of FIG. 1.

FIG. 3A is a MEMS-based VOA designed in accordance with the method of the present invention shown in an equilibrium or initial position.

FIG. 3B is the MEMS-based VOA of FIG. 3B shown in an actuated position.

FIG. 4 is close view of the input and output end faces of the optical fiber of the MEMS-based VOA of FIG. 3A.

FIG. 5 is an array of MEMS-based VOA's designed and used in accordance with the method of the present invention.

Detailed Description of the Preferred Embodiment

Referring now generally to the Figures and particularly to FIG. 1, a first preferred embodiment of the present invention, or invented VOA 2 includes an input photonic component 4, a movable focusing mirror 6, and an output photonic component 8. A light beam 10 exits the input photonic component 4 and travels toward the focusing mirror 6.

The focusing mirror 6 reflects and focuses the light beam 10 into a reflected and focused light beam 12. Two or a plurality of electrostatic mirror actuators 14, or actuators 14, actuate the focusing mirror 6 in at least one dimension. The movable focusing mirror 6, or focusing mirror 6, steers the reflected and focused light beam 12 to form a trajectory on a receiving face 18 of the output photonic component 8 as the mirror actuators 14 drive the focusing mirror 6 in at least one dimension.

The movable focusing mirror 6 may be or comprise, in various preferred embodiments of the present invention, a concave mirror, a diffractive mirror, a diffractive concave mirror, a Fresnel mirror, a Zone plate mirror, or another suitable movable focusing mirror known in the art.

The input photonic component 4 and the output photonic component 8 may each be or comprise, in various preferred embodiments of the present invention, a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a mirror or a collimator, or another suitable photonic component for transmitting and/or receiving the light beam.

The mirror actuators 14 may, in various preferred embodiments of the present invention, actuate the focusing mirror in one, two, or more dimensions. In addition, the mirror actuators 14 of the invented VOA 2 may each be or comprise, in various alternate preferred embodiments of the present invention, an actuator selected from the group consisting of an electro-mechanical actuator, an electro-static actuator, a piezo-electric actuator, a thermo-mechanical actuator, an electromagnetic actuator, and a polymer actuator. Where a mirror actuator 14 comprises a polymer actuator, the mirror actuator 14 may be or comprise an actuator selected from the group consisting of an electro-active

polymer actuator, an optical-active polymer, a chemically active polymer actuator, a magneto-active polymer actuator, an acousto-active polymer actuator and a thermally active polymer actuator.

The focusing mirror 6 and the mirror actuators 14 are integrated onto a substrate 20. The substrate 20 and one or more substrate elements 22 may each be or comprise a wafer. The substrate 20 and the substrate elements 22 may comprise suitable materials known in the art, such as a single wafer of glass or semiconductor material. The substrate 20 may be or comprise, in certain alternate preferred embodiments of the present invention, two or a plurality of coupled substrate elements 22. The substrate elements 22 may be individual wafers and may be bonded, adhered, or otherwise coupled with a suitable coupling technique known in the art.

In certain various preferred embodiments of the present invention the substrate 20 and substrate elements 22 may be or comprise suitable substrate materials known in the art, to include semiconductor material, glass, silica, ceramic, metal, metal alloy, and polymer. The semiconductor material may be or comprise suitable substrate materials, to include Silicon, Silicon Carbide, Gallium Arsenide, Gallium Nitride, and Indium Phosphide.

Referring now generally to the Figures and particularly to FIG. 2, the reflected and focused light beam 12 strikes the receiving face 18 at a strike circle 24, or spot 24. A center 26 of the spot 24 defines the one dimensional trajectory 16 as the spot 24 moves over receiving face 18. Additionally or alternatively, mirror actuators 14 may drive the focusing mirror 6 in at least two dimensions to steer the reflected and focused light beam 12 to form a two dimensional trajectory 28 on the receiving face 18 of the output

photonic component 8 and the focusing mirror 6. The mirror actuators 14 position the focusing mirror 6 in, one, two or more dimensions and thereby drives the center 26 of the spot 24 of reflected and focused light beam 12 along either the one dimensional trajectory 16 or the two dimensional trajectory 28.

Referring now generally to the Figures and particularly to FIG.'s 3A and 3B, a MEMS mirror VOA 29 is a MEMS-based device 29 designed and implemented according to the method of the present invention. The MEMS mirror VOA 29 has an input optical fiber 30, an output optical fiber 31 and a substrate 32. Substrate 32 comprises a first substrate element 33, bonded to a second substrate element 34. The substrate 32 further includes a third substrate element 35 bonded to the second substrate element 34. The substrate elements 33, 34, & 35 can each be wafers and/or made from a suitable semiconductor material by means of a suitable MEMS micro-machining process known in the art. The third substrate element 35 includes a frame 36 and a first movable electrode plate 38 and a second movable electrode plate 40. The MEMS mirror VOA 29 may further comprises one or more additional electrode plates 38 & 40 that enable the MEMS mirror VOA 29 to actuate the focusing mirror 6 in two or three dimensions and/or within as many as all six degrees of freedom of motion.

A concave mirror 42 is preferably a micro-mirror located in the central area between the first and second movable electrode plates 38 & 40, or first and second movable structures 38 & 40. The movable electrode plates 38 and 40 are affixed to or comprised by the concave mirror 42. A first electrostatic actuator 44 and a second electrostatic actuator 45 are formed in the substrate 32. The first electrostatic actuator 44 comprises a first actuator driver 46, a first fixed electrode plate 47 and the first movable

electrode plate 38. The second electrostatic actuator 45 comprises a second actuator driver 48, a second fixed electrode plate 49 and the second movable electrode plate 40. The actuator design of the first and second actuators 44 & 45 enables the controlled movement of movable electrode plates 38 and 40 by controlling the electrical state of the fixed electrode plates 47 and 49 via the drivers 46 & 48. Concave mirror 42 moves together with the first and second movable electrode plates 38 and 40. FIG. 3A shows first and second movable electrode plates 38 & 40 and concave mirror 42 in an equilibrium position when no force is applied to the first and second movable electrode plates 38 & 40 by the fixed electrode plates . FIG. 3B illustrates the position of the first and second movable electrode plates 38 & 40 and concave mirror 42 in an actuated position. As can be seen from FIG.'s 3A and 3B, changing the angular position of movable electrode plates 38 or 40 changes the angular position of concave mirror 42 and the direction of the light beam 12. Therefore light beam 12 can be spatially redirected by the interaction of the first and second fixed electrode plates 47 & 49 with the movable electrode plates 38 & 40.

Frame 36 is coupled with movable electrode plates 38 and 40 by suspensions 50 and 52. Suspensions 50 and 52 are strong enough to withstand mechanical forces applied to movable parts 38 and 40 during wafer processing, including wafer separation and die handling. Suspensions 50 and 52 are flexible enough to provide angular deflection of the movable electrode plates38 and 40 by the force applied by the first and second actuators 44 & 45. Suspensions 50 and 52 also provide electrical and/or magnetic and/or thermal connection of movable parts 38 and 40 with frame 36.

The MEMS mirror VOA 29 may alternatively or additionally include thermo-mechanical or bi-metallic actuators. Thermo-mechanical actuators can achieve larger forces and deflections compared to electrostatic and electromagnetic actuators. Where MEMS mirror VOA 29 includes thermo-mechanical actuators, the MEMS mirror VOA 29 may contain a heater (not shown) that heats at least a portion of the suspensions 50 and 52. This heating causes stresses in suspensions 50 and 52 that in turn cause angular displacement of movable electrode plates 38 and 40, whereby the concave mirror 42 is also angularly displaced.

There are several options for the heater or a heating structure. In a multi-level structure, the heating can be accomplished by imposing an electric current through a metal layer or a silicon layer, or both. The heater may be electrically and thermally coupled with the substrate 32. If the actuators 44 and 45 comprise thermo-mechanical bimetallic actuators an electrical connection with the substrate 32 can provide the necessary electrical current to the heater. A thermal connection between can provide a sufficient thermal resistance to both create the necessary temperature gradient across suspensions 50 and 52, yet be small enough to prevent overheating of the first and second movable structures 38 & 40.

Where MEMS mirror VOA 29 includes piezoelectric actuators, a piezoelectric material (not shown) can be applied to the top of the third substrate element 35 in suspensions 50 and 52. A voltage applied to the piezoelectric material changes the linear dimensions of the piezoelectric material, whereby suspensions 50 and 52 are bent and movable structures 38 and 40 are deflected. The concave mirror 42 will therefore be angularly displaced as the suspensions 50 and 52 are bent. A coupling of the actuators 44

& 45 with the substrate 32 provides for a pathway to deliver controlling voltages to the piezoelectric material.

The MEMS mirror VOA 29 is integrated and is wholly or partially comprised as a micro-electro-mechanical system. The concave mirror 42, the electrostatic actuators 44 and 45 and the substrate 32 are coupled with each other and integrated together. The input optical fiber 30 and an output optical fiber 31 are coupled with the substrate 32. The input optical fiber 30 has an input endface 56 and the output optical fiber 31 has a receiving endface 58.

The electrostatic actuators 44 & 45 actuate the mirror 42 in at least two dimensions and the suspensions 50 and 52 provide a restoring force to return the mirror 42 to an initial position when the mirror 42 is actuated out of the initial position of FIG. 3A. The electrostatic actuators 44 and 45 move the mirror 42 in an analog or approximately proportional fashion relating to a control, power or actuating signal, whereby the mirror 42 is at any point within a range of motion. The MEMS mirror VOA 29 thereby provides better selectability of attenuation than prior art systems that offer two or more discrete, pre set positions with a range of motion.

Referring now generally to the Figures, a preferred method of the present invention includes providing the concave mirror 42, the light beam 10, and the output optical fiber 31. The light beam 10 strikes the concave mirror 42. The actuators 44 & 45 move the concave mirror 42 to steer the reflected light beam 12 to strike the receiving endface 58 of the output optical fiber 31. The concave mirror 42 controllably forms the two dimensional trajectory 28 on the output optical fiber 31 by moving and thereby steering the light beam 12 to move across the receiving endface 58.

Referring now generally to the Figures and particularly to FIG. 4, FIG. 4 is a close view of the input endface 56 of the input optical fiber 30 and the output receiving endface 58 of the output optical fiber 31 of the MEMS-based device 29 of FIG. 3. The input endface 56 and the receiving endface 58 are both substantially planar and are substantially parallel to a planar surface 62 of the substrate 32. An input transmission axis 64 internal to the input optical fiber 30 terminates at the input endface 56 wherefrom the light beam 10 exits the input optical fiber 30. An angle $\theta 1'$ is defined as the angle between the input transmission axis 64 at and the planar surface 62 at the input endface 56. The input transmission axis 64 ends at the input endface 56 at the angle $\theta 1'$ selected from a range of angles from approximately 45 degrees to 90 degrees, or more optimally from a range of angles from approximately 75 degrees to 90 degrees. The light beam 10, as shown in FIG. 1, changes direction after leaving the input endface 56 due to refraction. This refraction causes a difference between the angle $\theta 1'$ and an angle $\theta 1$. The angle $\theta 1$ is equal to the angle of intersection between the light beam 10 and a plane 65, where the plane 65 is parallel with the input endface 56 and the receiving endface 58. As $\theta 1'$ increases towards 90 degrees, the difference between $\theta 1'$ and $\theta 1$ decreases.

An output transmission axis 66 internal to the output optical fiber 31 terminates at the output receiving endface 58. The reflected and focused light beam 12 of FIG. 1 partially or wholly enters the output optical fiber 31 via the output receiving endface 58. The output transmission axis 66 leads from the output receiving endface 58 at an angle $\theta 2'$ selected from a range of angles from approximately 45 degrees to 90 degrees, or more optimally from a range of angles from approximately 75 degrees to 90 degrees. The reflected light beam 12, as shown in FIG. 1, reflects from the focusing mirror 6 an angle

$\theta 2$, where $\theta 2$ is equal to the intersection angle between the reflected light beam 12 and the plane 65. The angled orientation of the optical fibers 30 and 31 and of their respective endfaces 56 and 58, in relation to the mirror, reduces an operating range of motion required by the mirror to provide a desired range of attenuation. The angle $\theta 2$ is equal to the angle of intersection between the output transmission axis 66 and the plane 65. The refraction of the light beam 10 that causes a difference between the angle $\theta 1'$ and an angle $\theta 1$ also contributes to a difference between $\theta 2$ and $\theta 2'$. The difference between $\theta 2$ and $\theta 2'$ contributed by the refraction occurring at input endface 56 similarly decreases as $\theta 1'$ approaches 90 degrees. It is understood that the value of $\theta 2$ is also affected by the position of the focusing mirror, whereas the constant value of angle $\theta 2'$ is determined by the orientation of the output fiber 31 and the planar surface 62.

It is further understood that the endfaces 56 and 58 are not, in certain alternate preferred embodiments of the present invention, co-planar, i.e. oriented within or approximately at a single plane. The endfaces 56 and 58, for example, are raised above the substrate planar surface 62 and closer to the concave mirror in certain alternate preferred embodiments of the present invention

Referring now generally to the Figures and particularly to FIG. 5, a MEMS VOA array 68 includes a plurality of MEMS-based VOA's 70, 72 and 74, or MEMS VOA 70, 72 and 74. Each MEMS VOA 70, 72, and 74 has an input optical fiber 70A, 72A and 74A, a concave mirror 70B, 72B and 74B, an actuator 70C, 72C, and 74C and an output optical fiber 70D, 72D and 74D. The optical fibers 70A, 72A, 74A, 70D, 72D and 74D are coupled with a first substrate element 76 and the concave mirrors are rotatably coupled to a second substrate element 78. The first substrate element 76 and the second

substrate element 78 are comprised within substrate 80 bonded, or adhered, or coupled by another suitable coupling means known in the art. A light beam λ1 passes through input optical fiber 70A and strikes mirror 70B. Mirror 70B steers light beam λ1 away from the best alignment with a receiving face 70E of output optical fiber 70D, whereby only a small fraction of light beam λ1 passes into the output optical fiber 70D through the receiving face 70E. Any optical signal being transmitted via light beam λ1 is thereby significantly attenuated by MEMS VOA 70.

Referring now to MEMS VOA 72, a light beam λ2 passes through input optical fiber 72A and strikes mirror 72B. Mirror 72B steers and focuses light beam λ2 directly at a receiving face 72E of the output optical fiber 72D, whereby a large percentage of light beam λ2 passes into the receiving face 72E. Any optical signal being transmitted via light beam λ2 is thereby not significantly attenuated by MEMS VOA 72.

Referring now to MEMS VOA 74, a light beam λ3 passes through input optical fiber 74A and strikes mirror 74B. Mirror 74B steers and focuses light beam λ3 at a point within VOA 74 that is between (1) the analogous positions to which λ1 is being steered to in VOA 70, and (2) the analogous position to which λ2 is being steered to in VOA 72. A larger percentage of light beam λ3 passes into a receiving face 74E than receiving face 70E is receiving of λ1. But a smaller percentage of light beam λ3 passes into the output fiber 74D than the input fiber 72D is receiving of λ2. Any optical signal being transmitted via light beam λ3 is thereby attenuated by MEMS VOA 74 at a level of attenuation intermediate between the attenuation of λ1 by MEMS VOA 70 and of λ2 by MEMS VOA 72.

The advantages of the MEMS VOA array 68 over singly packaged VOA's include cost reductions in packaging expenses on a per VOA basis. Further cost reductions are achieved in eliminating individual component optical alignment steps.

The present invention has been described in conjunction with the preferred embodiments. Although the present invention has been described with reference to specific exemplary embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the invention as set forth in the claims. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. As noted above, the present invention is applicable to the use, operation, structure and fabrication of a number of different VOA's. The present invention should not be considered limited to the particular examples described above, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention may be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon review of the present specification. The claims are intended to cover such modifications, devices and methods.

I claim:

1. A VOA for attenuating an optical signal, the optical signal transmitted via a light beam, and the VOA comprising:

a movable focusing mirror, the movable focusing mirror for reflecting, focusing and steering the light beam in a trajectory;

an actuator, the actuator operatively coupled with the movable focusing mirror, and the actuator for actuating the movable focusing mirror; and

an output photonic component, the output photonic component positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the photonic component.

2. The VOA of claim 1, wherein the movable focusing mirror is selected from the group consisting of a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

3. The VOA of claim 1, wherein the actuator is selected from the group consisting of an electro-mechanical actuator, an electro-static actuator, a piezo-electric actuator, a thermo-mechanical actuator, an electromagnetic actuator, and a polymer actuator.

4. The VOA of claim 3, wherein the polymer actuator is selected from the group consisting of an electro-active polymer actuator, an optical-active polymer, a chemically active polymer actuator, a magneto-active polymer actuator, an acousto-active polymer actuator and a thermally active polymer actuator.

5. The VOA of claim 1, wherein the output photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

6. The VOA of claim 1, wherein the actuator actuates the mirror in at least one dimension and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least one dimension.

7. The VOA of claim 1, wherein the actuator actuates the mirror in at least two dimensions and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least two dimensions.

8. The VOA of claim 1, wherein the movable focusing mirror, the actuator and the output photonic component are coupled to a substrate.

9. The VOA of claim 1, wherein the movable focusing mirror, the actuator and the output photonic component are integrated onto a substrate.

10. The VOA of claim 1, wherein the movable focusing mirror, the actuator and the output photonic component are fabricated on a substrate.

11. The VOA of claim 9, wherein the substrate comprises at least two substrate elements.

12. The VOA of claim 9, wherein the substrate comprises a plurality of substrate elements.

13. The VOA of claim 1, further comprising an input photonic component, the input photonic component for transmitting the light beam toward the mirror.

14. The VOA of claim 13, wherein the movable focusing mirror is selected from the group consisting of a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

15. The VOA of claim 13, wherein the actuator is selected from the group consisting of an electro-mechanical actuator, an electro-static actuator, a piezo-electric actuator, a thermo-mechanical actuator, an electromagnetic actuator, and a polymer actuator.

16. The VOA of claim 15, wherein the polymer actuator is selected from the group consisting of an electro-active polymer actuator, an optical-active polymer, a chemically active polymer actuator, a magneto-active polymer actuator, an acousto-active polymer actuator and a thermally active polymer actuator.

17. The VOA of claim 13, wherein the input photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

18. The VOA of claim 13, wherein the output photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a

Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

19. The VOA of claim 13, wherein the input photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

20. The VOA of claim 13, wherein the actuator actuates the mirror in at least one dimension and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least one dimension.

21. The VOA of claim 13, wherein the actuator actuates the mirror in at least two dimensions and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least two dimensions.

22. The VOA of claim 13, wherein the movable focusing mirror, the actuator, the output photonic component, and the input photonic component are coupled to a substrate.

23. The VOA of claim 13, wherein the movable focusing mirror, the actuator and the output photonic component, and the input photonic component are integrated onto a substrate.

24. The VOA of claim 13, wherein the movable focusing mirror, the actuator and the output photonic component, and the input photonic component are fabricated on a substrate.

25. The VOA of claim 19, wherein the substrate comprises at least two substrate elements.

26. The VOA of claim 19, wherein the substrate comprises a plurality of substrate elements.

27. A MEMS VOA for attenuating an optical signal, the optical signal transmitted via a light beam, and the MEMS VOA comprising:
a substrate;

a movable focusing mirror, the movable focusing mirror coupled with the substrate, and the movable focusing mirror for reflecting, focusing and steering the light beam in a trajectory;

an actuator, the actuator coupled with the substrate, and the actuator operatively coupled with the movable focusing mirror, the actuator for actuating the movable focusing mirror;

an input photonic component, the input photonic component coupled with the substrate, and the light beam emitting from the input photonic component and toward the movable focusing mirror; and

an output photonic component, the output photonic component coupled with the substrate and positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the output photonic component.

28. The MEMS VOA of claim 27, wherein the substrate comprises at least two substrate elements.

29. The MEMS VOA of claim 27, wherein the substrate comprises a plurality of substrate elements.

30. The MEMS VOA of claim 27, wherein the substrate is selected from the group consisting of semiconductor material, glass, silica, ceramic material, metal, metal alloy, and polymer.

31. The MEMS VOA of claim 30, wherein the semiconductor material is selected from the group consisting of Silicon, Silicon Carbide, Gallium Arsenide, Gallium Nitride, and Indium Phosphide.

32. The MEMS VOA of claim 27, wherein the movable focusing mirror is selected from the group consisting of a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

33. The MEMS VOA of claim 27, wherein the actuator is selected from the group consisting of an electro-mechanical actuator, an electro-static actuator, a piezo-electric actuator, a thermo-mechanical actuator, an electromagnetic actuator, and a polymer actuator.

34. The MEMS VOA of claim 33, wherein the polymer actuator is selected from the group consisting of an electro-active polymer actuator, an optical-active polymer, a chemically active polymer actuator, a magneto-active polymer actuator, an acousto-active polymer actuator and a thermally active polymer actuator.

35. The MEMS VOA of claim 27, wherein the output photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

36. The MEMS VOA of claim 27, wherein the input photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

37. The MEMS VOA of claim 36, wherein the output photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

38. The MEMS VOA of claim 27, wherein the actuator actuates the mirror in at least one dimension and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least one dimension.

39. The MEMS VOA of claim 27, wherein the actuator actuates the movable focusing mirror in at least two dimensions and the movable focusing mirror reflects, focuses and steers the light beam within a trajectory having at least two dimensions.

40. A MEMS VOA for attenuating an optical signal, the optical signal transmitted via a light beam, and the MEMS VOA comprising:

a substrate;

a movable focusing mirror, the movable focusing mirror coupled with the substrate, and the movable focusing mirror for reflecting, focusing and steering the light beam in a trajectory;

an actuator, the actuator coupled with the substrate, and the actuator operatively coupled with the movable focusing mirror, the actuator for actuating the movable focusing mirror;

an input wave guide, the input wave guide having an input transmission axis and an input endface, and the input wave guide coupled with the substrate, and the light beam emitting along the transmission axis, from the input endface, and toward the movable focusing mirror; and

an output wave guide, the output wave guide having an output endface and an output transmission axis, and the output endface positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the output wave guide.

41. The MEMS VOA of claim 40, wherein the input endface further comprises an input planar surface that is substantially planar and parallel to a planar surface of the substrate, and the input transmission axis

intersects the input planar surface at an angle within a range of 75 degrees to 90 degrees.

42. The MEMS VOA of claim 40, wherein the input endface further comprises an input planar surface that is substantially planar and parallel to a planar surface of the substrate, and the input transmission axis intersects the input planar surface at an angle within a range of 45 degrees to 90 degrees.

43. The MEMS VOA of claim 40, wherein the output endface further comprises an output planar surface that is substantially planar and parallel to a planar surface of the substrate, and the output transmission axis intersects the output planar surface of the output put endface at an angle within a range of 75 degrees to 90 degrees.

44. The MEMS VOA of claim 40, wherein the output endface further comprises an output planar surface that is substantially planar and parallel to a planar surface of the substrate, and the output transmission axis intersects the output planar surface of the output put endface at an angle within a range of 45 degrees to 90 degrees.

45. The MEMS VOA of claim 43, wherein the input endface further comprises an input planar surface that is substantially planar and parallel to the planar element of the substrate, and the input transmission axis intersects the input planar surface at an angle within a range of 75 degrees to 90 degrees.

46. The MEMS VOA of claim 44, wherein the input endface further comprises an input planar surface that is substantially planar and parallel to the planar element of the substrate, and the input transmission axis intersects the input planar surface at an angle within a range of 45 degrees to 90 degrees.

47. The MEMS VOA of claim 41, wherein the input wave guide is an optical fiber.

48. The MEMS VOA of claim 43, wherein the output wave guide is an optical fiber.

49. The MEMS VOA of claim 45, wherein the input wave guide and output wave guide are optical fibers.

50. A method of attenuating an optical signal, the optical signal transmitted via a light beam, the method comprising:

providing a movable focusing mirror, a light beam, and a photonic component;

aiming the light beam at the movable focusing mirror;

reflecting and focusing the light beam from the movable focusing mirror as a reflected light beam;

moving the movable focusing mirror to steer the reflected light beam onto a receiving surface of the photonic component, whereby the portion of the light beam absorbed by the photonic component is controlled.

51 The method of claim 50, wherein the movable focusing mirror is selected from the group consisting of a Fresnel, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

52. The method of claim 50, wherein the photonic component is selected from the group consisting of a wave guide, a planar wave guide, an optical fiber, an optical lens, a spherical lens, an aspherical lens, a ball lens, a GRIN lens, a C-lens, a lens system, a prism, a collimator, a mirror, a Fresnel mirror, a Zone plate mirror, a concave mirror, a diffractive mirror, and a diffractive concave mirror.

53. A MEMS VOA array for attenuating an optical signal, the optical signal transmitted via a plurality of light beams, and the MEMS VOA array comprising:

a substrate;

a plurality of VOA's, each VOA comprising a movable focusing mirror, an actuator, an input optical fiber, and an output optical fiber;

each movable focusing mirror coupled with the substrate, and the movable focusing mirror for reflecting, focusing and steering a light beam in a trajectory;

each actuator coupled with the substrate, and the actuator operatively coupled with the movable focusing mirror, the actuator for actuating the movable focusing mirror;

an input optical fiber, the input optical fiber coupled with the substrate, and the light beam emitting from the input optical fiber and toward the focusing movable mirror; and

an output optical fiber, the output optical fiber coupled with the substrate and positioned to receive at least part of the light beam reflected from the movable focusing mirror when the light beam is steered towards the output optical fiber.

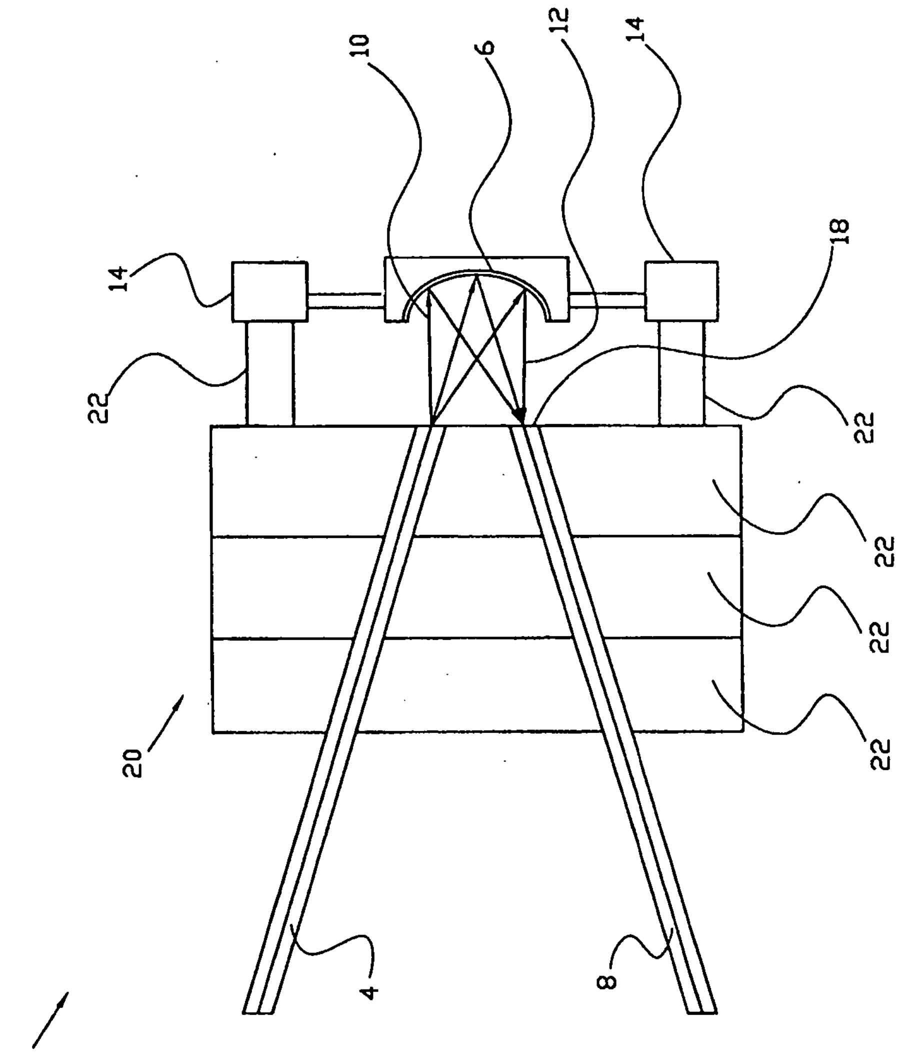

FIG. 1

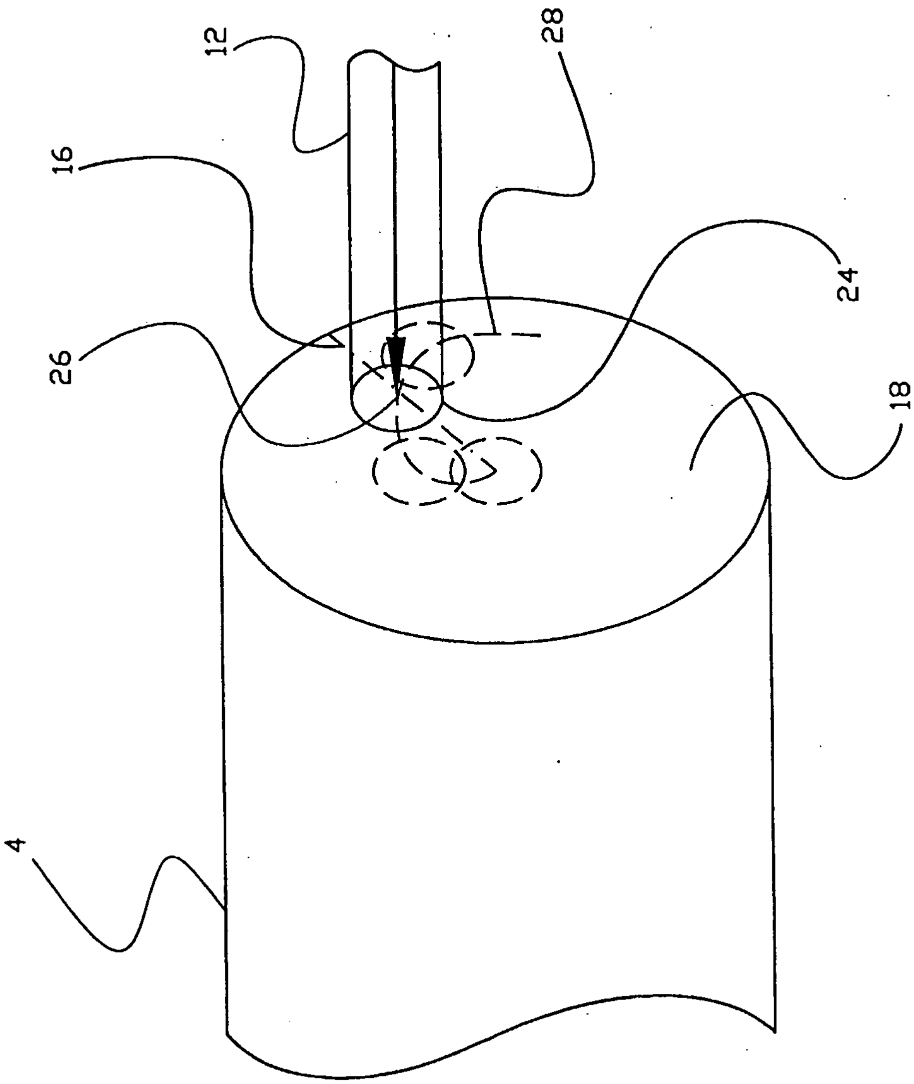

FIG. 2

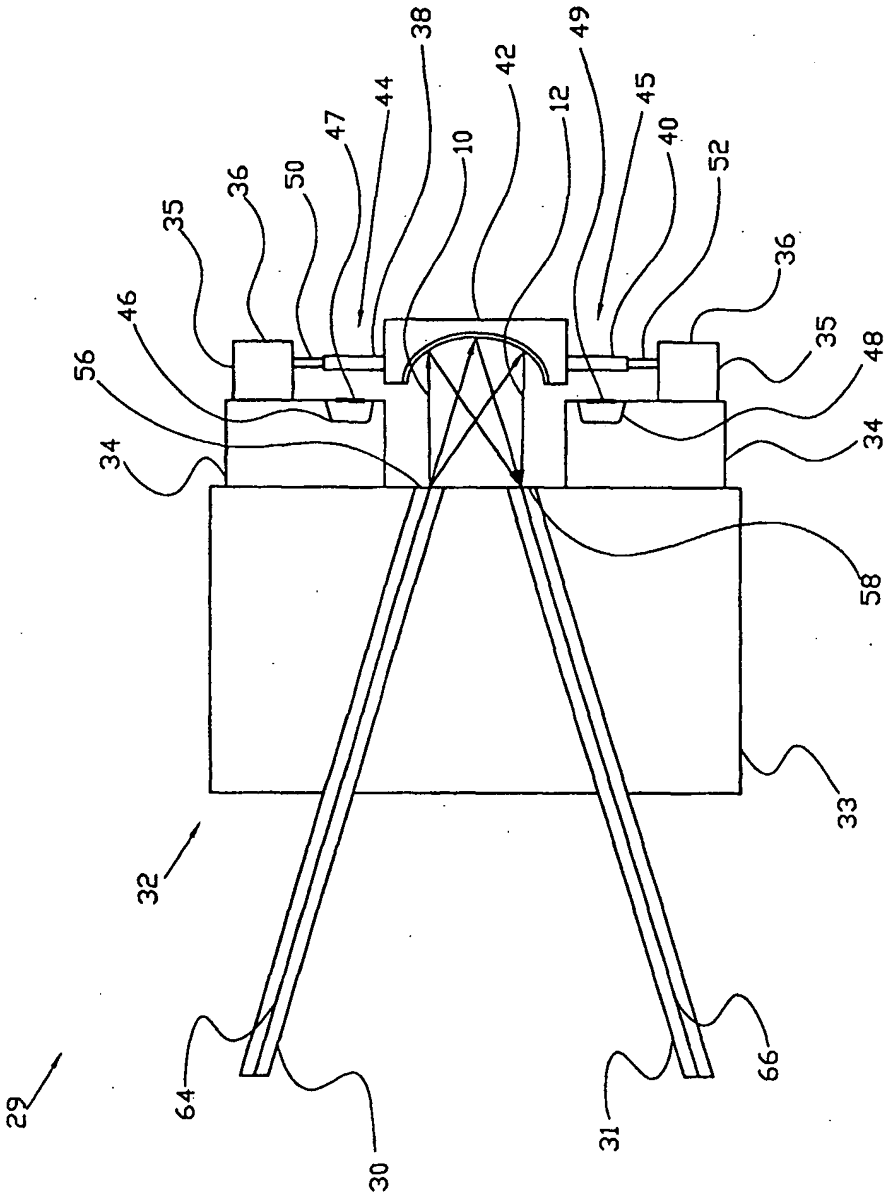
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FIG. 3A

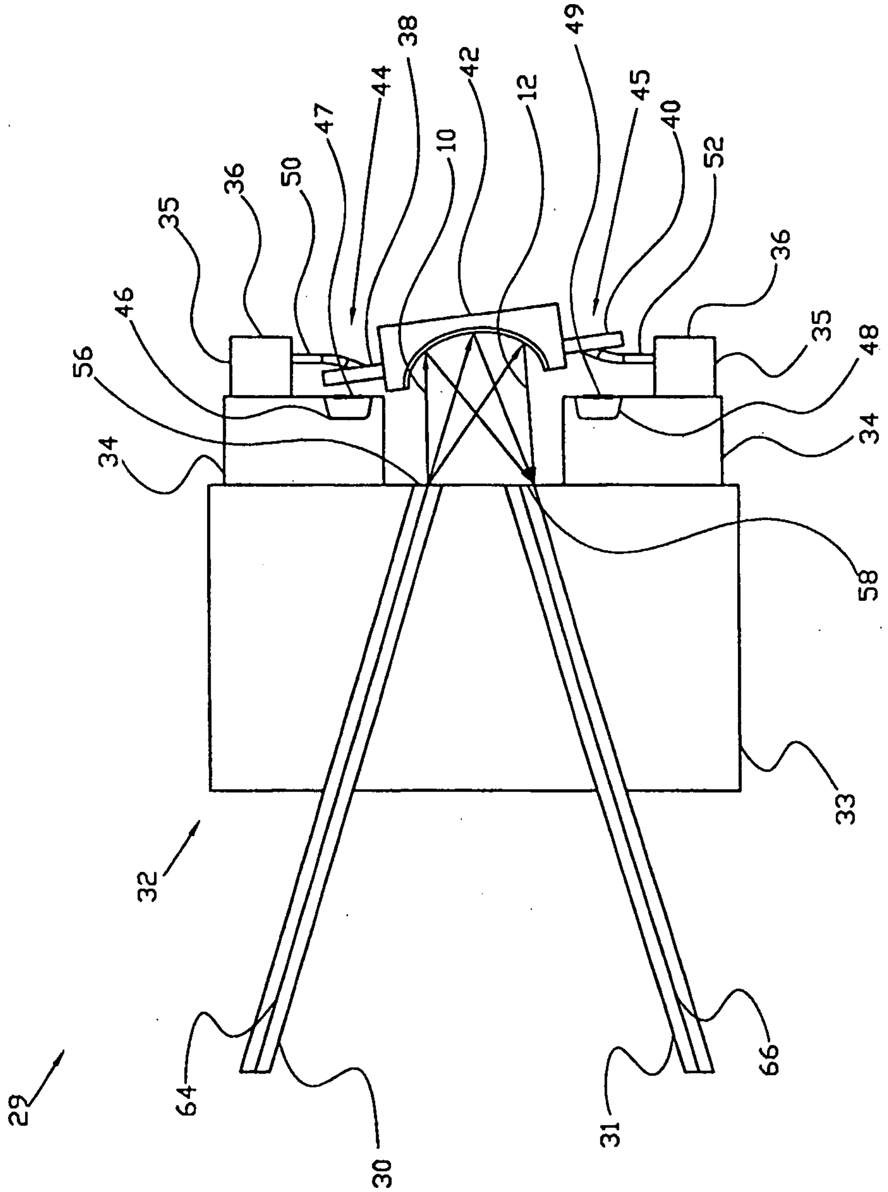
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FIG. 3B

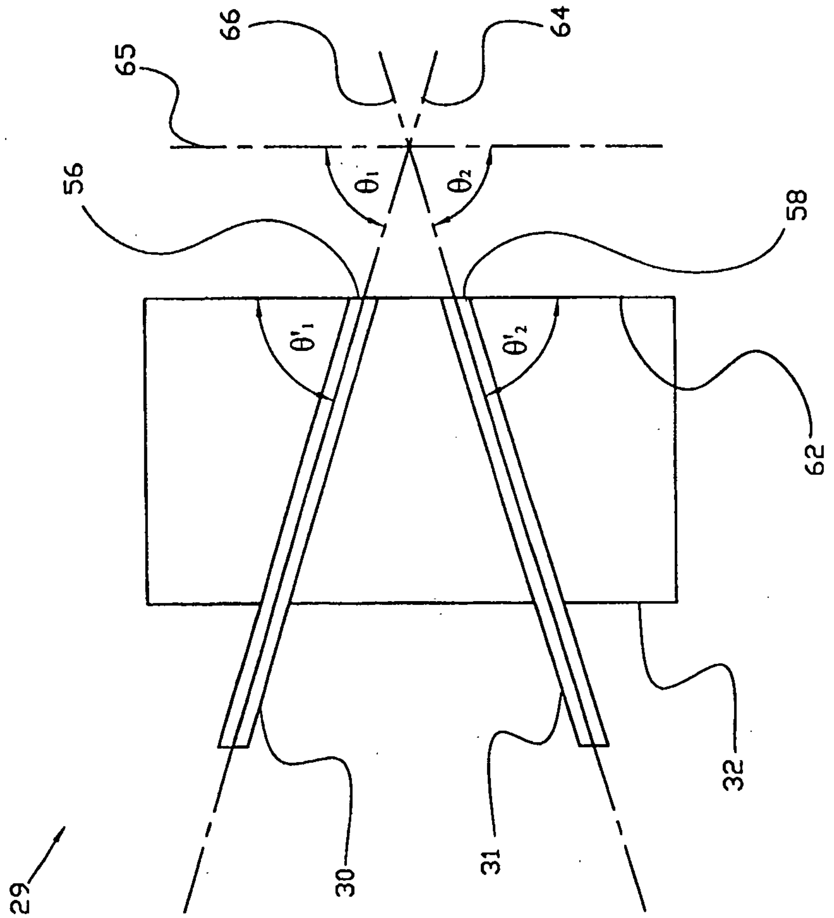
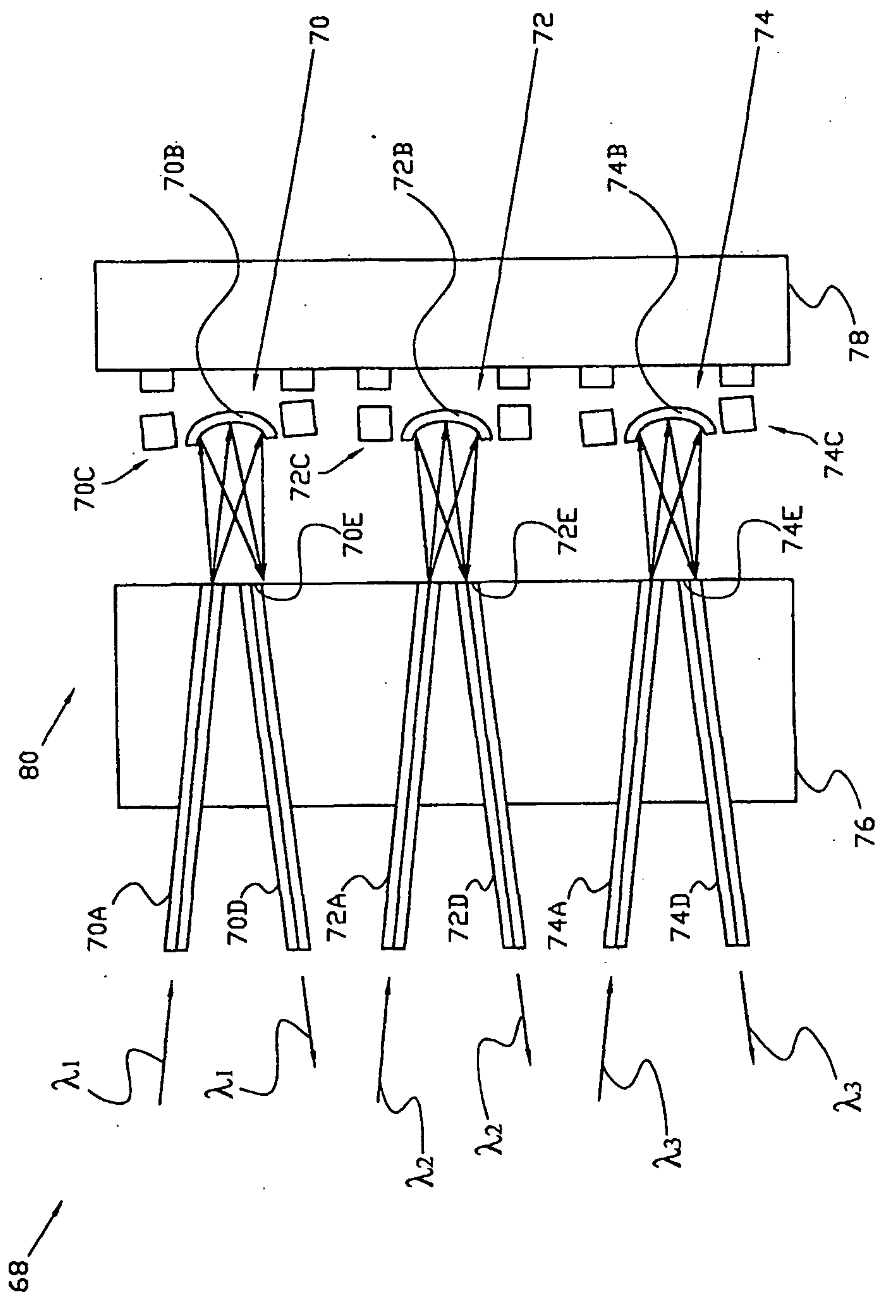


FIG. 4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70B
72B
74B
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70C
72C
74C
70E
72E
74E
80
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70A
70D
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72D
74A
74D
λ_1
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λ_2
λ_2
λ_3
λ_3
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FIG. 5

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/26 G02B26/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, COMPENDEX, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 915 063 A (COLBOURNE PAUL ET AL) 22 June 1999 (1999-06-22)	1-3,5,6, 13-15, 17-20, 50-52
	column 3, line 44 -column 4, line 63 column 6, line 8 - line 36; figures 1,6,7	
Y		1-3,5,6, 8-15, 17-20, 22-33, 35-38, 40-53
Y		1-3,5-7, 13-15, 17-21, 27,32, 33, 35-40, 50-52
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 March 2003	19/03/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Besser, V

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 01 06543 A (CHERTKOW ROBERTO IGAL ;MEMLINK LTD (IL)) 25 January 2001 (2001-01-25) page 9, line 20 -page 11, line 12 page 13, line 24 -page 14, line 32 page 25, line 1 -page 26, line 11; figures 1,5,20	1-3,5,6, 8-15, 17-20, 22-33, 35-38, 40-53
Y	RIZA N A ET AL: "Fault-tolerant variable fiber-optic attenuator using three-dimensional beam spoiling" , OPTICS COMMUNICATIONS, NORTH-HOLLAND PUBLISHING CO. AMSTERDAM, NL, VOL. 185, NR. 1-3, PAGE(S) 103-108 XP004219461 ISSN: 0030-4018 page 104, paragraph 2 -page 105; figure 1	1-3,5-7, 13-15, 17-21, 27,32, 33, 35-40, 50-52
X	US 6 031 946 A (BISHOP DAVID JOHN ET AL) 29 February 2000 (2000-02-29) cited in the application column 8, line 17 - line 46; figures 8A,B	1-3,5,6, 13-15, 17-20, 50-52
X	US 4 516 827 A (HUTCHISON WANDA S ET AL) 14 May 1985 (1985-05-14) column 2, line 59 -column 3, line 30; figures 1,2	1,2,5,6, 13,14, 17-20, 50-52
A	WO 01 31714 A (NASA) 3 May 2001 (2001-05-03) page 3 -page 4; claim 1; figure 1	3,4,15, 16,33,34

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 5915063	A	22-06-1999	CA	2230664	A1	15-07-1998
WO 0106543	A	25-01-2001	AU	6012100	A	19-02-2001
			AU	6012500	A	05-02-2001
			EP	1218790	A2	03-07-2002
			GB	2367906	A	17-04-2002
			WO	0109653	A1	08-02-2001
			WO	0106543	A2	25-01-2001
			US	2002009256	A1	24-01-2002
			AU	6178400	A	18-06-2001
			WO	0143450	A2	14-06-2001
US 6031946	A	29-02-2000	NONE			
US 4516827	A	14-05-1985	NONE			
WO 0131714	A	03-05-2001	AU	1101201	A	08-05-2001
			AU	1340501	A	08-05-2001
			AU	1436801	A	08-05-2001
			AU	2039801	A	08-05-2001
			WO	0131714	A1	03-05-2001
			WO	0131715	A1	03-05-2001
			WO	0131716	A1	03-05-2001
			WO	0130875	A2	03-05-2001
			US	6515077	B1	04-02-2003